

Sugar Platform Process Integration Project September 2004 Interim Stage Review Meeting

Review Panel Input and NREL Responses

The Process Integration Project seeks to advance understanding of enzyme-based cellulose hydrolysis technology focusing on use of a model feedstock (corn stover) and process relevant designs to investigate integrated processing. The Biomass Program conceived this project, initiated in 2000, as a commercial-track project within the stage gate project management framework with the ultimate goal of facilitating commercialization of biomass refining technology in the United States.

In 2003, the project transitioned to a research-track Stage B project having fulfilled its role as a placeholder for a commercial-track project. On September 15, 2004, an Interim Stage review meeting was in Washington, D.C. before a seven-member review panel with industry and DOE Office the Biomass Program representatives. The objectives of the review meeting were 1) to present our recent accomplishments and future work recommendations and 2) to solicit feedback from reviewers and other interested parties on future project direction and priorities.

Input is presented below on the three main activities for this project: corn stover variability, biomass compositional analysis, and integrated processing, and on large view issues that are generally outside the scope of this project, but will be presented and briefly discussed. Our responses follow the enumerated input from the review panel.

Large View Issues

1. The answer to many questions raised at the meeting was that the activity resides in a different part of the Biomass Program. However, systems solutions are required and fragmentation of the overall effort into manageable sized projects should not be allowed to silo the Program.
 - This issue will be brought to the attention of Biomass Program management, but we agree that systems solutions are needed and that coordinated efforts are required between the Feedstock, Sugar, and Products Platforms.
2. There is no capital cost reduction target. NREL has capital cost modeled, but inclusion of depreciation in the MESP is not an adequate reflection of the barrier of raising large capital. Capital reduction should be targeted and tracked.
 - Again this is another issue that will be brought to the attention of Biomass Program management. We have already initiated work (high solids pretreatment and enzymatic saccharification) targeted at capital cost reductions, however, a concerted effort will be required to identify other areas for capital cost reductions and to develop appropriate metrics and tracking methodologies.

Feedstock Variability

3. Efforts to piggyback on work being performed by the USDA and others are good and should continue. You not only obtain well-characterized samples at very low cost, but add substantial value to the studies being performed by the researchers that provided the samples.
 - We will continue to develop relationships with collaborators regarding corn stover compositional variability. Where possible, we will participate in existing field studies that can be leveraged to help uncover the major genetic and environmental causes of that variation. We will continue to cultivate productive collaborations with USDA, Land Grant Universities and plant biotechnology industry researchers.
4. Need to extend the variability studies to determine the impact of corn stover variability on pretreatability (sugar yields), enzymatic cellulose hydrolysis, and fermentability. There is a theoretical impact based on carbohydrate content; how does it play out in final yields?
 - Feedstock variability work over that last few years has determined the extent of corn stover variability as a function of a number of genetic and environmental factors and its impact on process economics. In a parallel effort, integrated processing work has developed some data on the affect of stover variability on pretreatability and enzymatic cellulose hydrolysis yields. We will continue this work under integrated processing using new stover lots to be acquired under this task. We will utilize the help of INEEL and other contacts we have developed (see #3 above) to acquire 1-2 ton stover lots for continuing this work. However, there are no plans to rigorously assess fermentability of hydrolysates, but this issue will be examined this year in the integrated processing task.
5. Need to expand interface to other areas to allow studies of impact of storage on feedstock composition, pretreatability, enzymatic cellulose hydrolysis and fermentability.
 - This work should be accomplished in collaboration with the Feedstock Platform that would plan and execute a collection and storage study, presumably beginning in FY05. Materials produced by this effort would be sent to NREL for conversion testing in FY06.

Integrated Processing

6. Perform thin studies that indicate problems and generate representative results, that is, determine the problem, skip the solution. In-depth studies that provide solutions are not justified because they will not be generally applicable across a range of processes.
 - We agree with this suggestion and work during the next fiscal year is focused on identifying problems and/or showstopper issues. Specific elements of the project aligned with this suggestion include an

investigation of the effect of recycle water (backset) on process performance and a first-of-a-kind effort to benchmark integrated process performance for conversion of corn stover to ethanol.

7. Enzymatic saccharification time is too long and needs to be characterized with unwashed materials, that is, with background components (non-sugars) present during enzymatic saccharification. Determine components that are inhibitory to the cellulases (e.g., Maillard reaction products) and perform spiking studies to determine what chemicals inhibit cellulases.
 - We agree that enzymatic saccharification times are too long. Advances in pretreatment technology as well as efforts by the enzyme manufacturers to improve cellulase are expected to reduce saccharification times. We will begin efforts to understand the effect of background sugars and other inhibitory component in hydrolysate on enzymatic saccharification, with a focus on assessing performance at higher solids concentrations. Although this work is related to efforts in this project, it will be performed under another task (Pretreatment and Enzymatic Hydrolysis Task) in the Sugar Platform.
8. Move forward efforts to characterize waste streams; three years away is too late for those studies to be useful. Also, generate real data on thin stillage evaporate, for example. What is in it besides water? Are any of the streams or residues appropriate for putting back on the fields?
 - We agree to move the priority of wastewater characterization work forward, but will not be able to begin this work until FY06. Work this year that will set the stage for the future efforts in this area include benchmarking integrated process performance and determining the effect of recycle water (backset) on process performance, both of which are necessary so that process relevant wastewater can be generated.
9. Examination of the impact of backset on pretreatment performance, enzyme cellulose hydrolysis, and fermentation performance is very important and should be a high priority.
 - As discussed in # 8 above, we will begin work this year to characterize the effect of backset on fermentation performance.
10. Examining the gypsum question is low priority and should not be undertaken. The fact that gypsum is an issue was an important recognition, but the solution will be unique to each process and approaches for handling gypsum are well understood from existing industries.
 - We will eliminate our plans this year to characterize the gypsum residue. However, we may propose to continue this work in the future should dilute sulfuric acid pretreatment continue to be a front-running pretreatment technology.

11. Advance efforts to understand new feedstocks and new pretreatments.
 - Near-term process integration task work will continue to focus on the use of corn stover and dilute acid pretreatment. However, we propose to begin efforts in the next few years to use new feedstocks and pretreatment technologies as promising alternatives are identified. Initial work to characterize different feedstocks and alternative pretreatment technologies will start this year in the Pretreatment and Enzymatic Hydrolysis task, which should provide guidance for future efforts in the Process Integration task.
12. Interface Question: What is the root cause of biomass recalcitrance? Generate residue that can be characterized, both compositionally and structurally.
 - The Targeted Conversion Research Task of the Sugar Platform is investigating the issue of biomass recalcitrance. However, this task is able to generate representative residue samples and will do so as needed.

Compositional Analysis

13. Develop on-line monitoring capability, especially for monitoring the enzymatic saccharification reactor. Enzymatic saccharification is the least understood of all the unit operations. The second area for application of on-line monitoring would be in the fermentation reactor.
 - We would also add that we consider on-line monitoring of pretreatment as an equally important area of investigation. We have purchased and installed spectroscopic probes that can be used for these purposes. During FY05, we will begin developing methods for collecting robust spectra in saccharification reactors and fermentors as well as continuing efforts to monitor pretreatment products. This work will parallel efforts to improve wet chemical methods for characterizing the solid and liquid phases of process samples from these unit operations.
14. There is little point in trying to develop process control strategies based on on-line monitoring. There is no clear target for what is being controlled and the control parameters will be process specific.
 - This point is clearly understood and we proposed to only investigate probes and various methodologies for on-line process monitoring in the near future. Development of process control strategies would only become an activity if conducted by request of and in collaboration with an industrial partner.
15. Functional group based lignin determinations is an area that should be pursued, as well as work to characterize chemical changes to lignin during and after pretreatment.
 - This is a complex issue that will be investigated during FY05 with the goal of making recommendations for FY06 work. Many unique tools are

available at NREL for application to this challenge; however, subcontractors may perform much of the work.

Other Issues

16. Utilizing the Stage-Gate criteria in the preparation and presentation is excellent, however, it doesn't make a good critique form. The Reviewer form should include criteria for 1) what was well done and should be done, 2) what was not well done and/or should be dropped, 3) what is missing and/or should be added, 4) is the plan solid and adequately resourced.

- The critique form for future review meetings will incorporate these suggestions.

17. The presentation of the Stage-Gate Criteria and how they were addressed as an up-front presentation was very effective.

- We will continue with this format.

18. The presentations were very effective at setting the table with explanations of why and what was going to be presented later before jumping into technical descriptions.